Introduction

This chapter provides a more detailed exposition of the Loran-C system. In particular, a more technical presentation of the logic of hyperbolic systems is given, along with additional details on chains, signal propagation, ASF corrections, chain coverage, and salient characteristics of the transmitted signal. Chapter III extends this discussion to loran accuracy and its determinants, and methods for plotting positions.

Loran Transmitters, Chains, and Some Basic Definitions

As noted in Chapter I, a basic element of the Loran-C system is the loran chain. This chain consists of three or more stations (generally abbreviated LORSTAs for loran stations), including a master and at least two secondary transmitters. (Each master-secondary pair enables determination of one LOP, and two LOPs are required to determine a position.) Each Loran-C chain provides signals suitable for accurate navigation over a designated geographic area termed a coverage area. (The limits of each chains coverage area are given in Appendix B, and discussed in conceptual terms in this chapter and in Chapter III.) The coverage areas of the various Loran-C chains overlap somewhat, and there are many areas in the United States and nearby coastal waters where two (or more) chains can be received and used for navigation.[1] Criteria for selection of the most appropriate chain for navigation in areas covered by more than one chain are discussed in Chapter III.

Table II_1 identifies the ten Loran-C chains that provide coverage of the United States and contiguous areas, along with their common abbreviations, GRI designators (defined and discussed below), and the year that each chain was first completed. Closure of the so-called mid-continent gap[2] was completed with the commissioning of the NOCUS and SOCUS chains in 1991_an event marked with much pageantry as a sort of navigational equivalent of the completion of transcontinental railway of yesteryear.

Loran-C transmitters vary in radiated power from less than 200 kW (kilowatts) to over 2 MW (megawatts). To lend some perspective, the radiated power output of a typical AM station in the United States might be 5 kW. For FM transmissions the typical output would be larger, say 50 kW. Exact comparisons of power output are difficult to make, because the loran transmits only pulses. Nonetheless, in semi-quantitative terms at least, loran transmitters are quite powerful. Among other factors, the radiated power controls the range at which a usable signal can be received and, therefore, the coverage area of the chain.

Some transmitters have only one function (i.e., to serve as a master or secondary in a particular chain), but many transmitters are dual rated, meaning that these can serve one function in one chain, and yet another in a neighboring chain. For example, the Dana, IN, transmitter serves as the Zulu secondary in the NEUS (9960) chain, and also as the master transmitter for the Great Lakes (8970) chain. Dual rating is desirable because, other things being equal, land acquisition costs and siting difficulties are reduced.

Signal Characteristics and Some Important Definitions

Characteristics of the transmitted Loran-C signal are discussed in some detail below, but briefly, the transmitted signal consists of a series or group of pulses (each of a defined waveform discussed later). For the master signal, a series of nine pulses are transmitted (eight spaced 1,000 usec apart, followed by a ninth 2,000 usec later). (Pulsed transmission reduces the power requirements for system operation, assists signal identification, and enables precise timing of the signals.) Secondaries transmit a series of only eight pulses, each spaced 1,000 usec apart. This difference in the number of pulses, among other properties of _he signal, enables some loran receivers to distinguish the signals from the master from those of the secondary stations. (Most receivers use phase codes, discussed below, for this purpose, however.) The master and each secondary in the chain transmit in a specified and precisely timed sequence. First, the master station transmits. Then, after an interval sufficient to allow the master signal to propagate throughout the coverage area, the first secondary in sequence transmits, 3 and so forth. Normally, the secondary stations transmit in the alphabetical order of their letter designator e.g., Whiskey before X-ray before Yankee, etc. The secondary transmission is timed as follows: after the master signal reaches the next secondary in sequence, this secondary waits an interval, termed the secondary coding delay SCD) or simply coding delay (CD), to transmit. The total elapsed time from the master transmission until the secondary transmission is termed the emission delay (ED). The ED is equal to the sum of the time for the master signal to travel to the secondary (termed the baseline travel time or baseline length (BLL)) and the CD. Next, other secondaries (each with a specified CD/ED) transmit in sequence. The sequence is completed when the master again transmits the nine pulse group.

The length of time between successive transmissions of the masters pulse groups is termed the group repetition interval (GRI), and is expressed in microseconds (usec). The GRI designator is the GRI divided by ten, and is used as a symbol to identify and designate the loran chain. [4] Thus, the interval between successive transmissions (GRI) of the master pulse group for the Northeast US (NEUS) chain is 99,600 usec (about 0.1 sec), so the GRI designator for this chain is 9960. The GRI is chosen for each chain to be sufficiently large so that the signals from the master and each secondary in the chain have sufficient time to propagate throughout the chains coverage area before the next cycle of pulsed transmissions begins.

Continuing the example of the NEUS (9960) chain, the CDs and BLLs for the various secondary stations in this chain are Whiskey (CD 11,000 usec/BLL 2,797.20 usec), X-ray (CD 25,000 usec/BLL 1,969.93 usec), Yankee (CD 39,000 usec/BLL 3,221.64 usec), and Zulu (CD 54,000 usec/BLL 3,162.06 usec). This information is essential for computation of theoretical time differences (TDs) or loran LOPs, as illustrated below.

As a point of interest, dual-rated stations are periodically faced with an impossible task of radiating two overlapping pulse groups at the same (or nearly the same) time. To resolve this difficulty, one of the signals is blanked or suppressed during this time period. Priority blanking occurs when the same signal is always blanked, whereas alternate blanking occurs when blanking alternates between the two

rates. The type of blanking used for dual-rated stations is shown in
the data sheets given in Appendix B.

The stations in the loran chain transmit in a fixed sequence which
ensures that TDs can be measured throughout the coverage area. The
length of time in usec over which this sequence of transmissions from
the master and the secondaries takes place is termed the Group
Repetition Interval (GRI) of the chain.
All Loran-C chains operate on the same frequency (100 kHz), but are
distinguished by the GRI of the pulsed transmissions. GRIs for each
chain, together with CDs and EDs for each secondary in the chain are
also given in Appendix B.

Chain Configuration
The physical locations of the master and secondary transmitters (among
other factors) is an important determinant of both the accuracy and
coverage area of the Loran-C chain. Although the configuration (site
pattern of the transmitters) of each loran chain differs, it is
convenient to group these configurations into three generic categories;
the Triad (master and two secondaries), the Wye (master and three
secondaries in a spatial arrangement roughly resembling the letter Y),
and the Star (master and four or more secondaries roughly resembling a
star in appearance), as illustrated in Figure II_1. For example, the
Icelandic (9980) and Labrador (7930) chains are illustrations of
Triads, the North Pacific (9990) is a Wye, and the NEUS (9960) is in a
Star configuration.

These generic configuration categories are only approximate
descriptions the NEUS (9960) chain, for example, would be classified as
a star in this taxonomy but, as can be seen from Figure II-2[6] , the
resemblance is not literal. Interestingly enough, each transmitter in
the 9960 chain is dual rated; the Zulu secondary is discussed above,
the master, located in Seneca, NY, also serves as the X-ray secondary
for the Great Lakes (8970) chain, the Yankee secondary, located in
Carolina Beach, NC, also serves as the Zulu secondary for the SEUS
(7980) chain, the X-ray secondary, located in Nantucket, MA, also
serves as X-ray secondary for the Canadian East Coast (5930) chain, and
finally, the Whiskey secondary, located in Caribou, ME, also serves as
the master station for the Canadian East Coast (5930) chain.

The chain configuration is an important determinant of the coverage and
navigational accuracy of the chain. Three common configurations in use
are the Triad, Wye, and Star.

The coverage area (discussed in Chapter III) for the NEUS (9960) chain
is also shown in Figure II_2 enclosed by the long dashed lines. In
this chain the dimensions of the coverage area are each nearly 1,000 NM
in length an area several hundred thousand square miles in extent. Off-
shore coverage extends several hundred miles.

Other Definitions

The geographic line (technically the arc segment of the great circle)
connecting the master and each secondary is termed the baseline for the
master-secondary pair. The length of the baseline (in nautical miles)
varies with the chain and the individual master-secondary pair, but is
typically several hundred miles. Other points on this same great

circle containing the baseline (i.e., on the extension of the baseline
beyond the two stations joined) are part of what is termed the baseline
extension. As noted below, navigational use of a particular master-
secondary pair in the area of the baseline extension is problematic.
(Baseline extensions are shown on nautical charts, as discussed in
Chapter VI.)

Key technical terms defined in this section include GRI, ED, CD,
baseline, baseline travel time, and baseline extension.

Hyperbolic Systems: A Second Look

As noted in Chapter I, hyperbolic navigation systems function by
measuring the time differences in reception of signals from the master
and secondary transmitters. This chapter expands upon the basic idea of
the hyperbolic system with particular emphasis on the Loran-C system.
This section is fairly technical, and may be skipped by the reader
uninterested in such detail. Overall, the key technical points are
simple enough. First, the locus of points of constant difference in
distance from two stations is described by a mathematical function
termed a hyperbola. Second, the same is true for time differences
(assuming a constant propagation velocity). Therefore, LOPs of constant
TDs are likewise hyperbolas. Finally, the real world is slightly more
complex than the assumption of a constant propagation velocity would
indicate. Precise calculations of the physical location of loran LOPs
require a series of correction factors to be applied to account for the
fact that loran waves slow down over seawater or land (compared to
propagation through the atmosphere).

Hyperbolic Geometry On a Plane

To be concrete, suppose that (as some ancients did) the earth were a
flat plane, defined by the usual rectangular (X, Y) coordinate system,
where the units of the X and Y axis are in nautical miles from an
origin located at the point (0,0). Now suppose that two loran stations
are located on this lattice, a master station located at the point
M=(Xm, Ym) = (-200, 0) along the X-axis, and an X-ray secondary station
at the point S = (Xs, Ys) (200, 0)-some 400 NM to the right along the
X-axis. Consider an arbitrary point A = (Xa, Ya) on the lattice. From
elementary plane geometry, the distance (in nautical miles) from point
A to the master M, denoted d_{am}, is:

$$d_{am} = ((Xa - Xm)^2 + (Ya - Ym)^2),^{0.5} \qquad (II-1)$$

Or, in terms of the defined location of the master station, equation
(II_1) reduces to:

$$d_{am} = ((Xa + 200)^2 + Y^2a).^{0.5} \qquad (II-2)$$

Likewise, the distance from point A to the secondary, denoted d_{as}, is
given by:

$$d_{as} = ((x \quad a -200)^2 + y^2a).^{0.5} \qquad (II-3)$$

Finally, the difference between these distances, denoted Z, is given
by:

$$Z = d_{am} - d_{as} \qquad\qquad\qquad\qquad (II-4)$$

$$Z = ((Xa + 200)^2 + Y_a^2)^{.0.5} -$$

$$((X_a - 200)^2 + y^2a)^{.0.5} \qquad\qquad (II-5)$$

Figure II_3 shows how this distance difference function, Z, varies with the location of the point A in the plane. (This figure is truncated at Z = -350 (point A 350 miles chosen to the master than to the secondary) and at Z = 350 (point A 350 miles closer to the secondary than to the master).

A more typical presentation of this difference function is to take slices of this surface at various values for Z. These slices (referred to as level curves, or constant differential distance contours) are shown in Figure II_4. Mathematically, these curves are hyperbolas. On a sphere (rather than the plane used in Figures II_3 and II_4) these would be spherical hyperbolas, while on the slightly nonspherical earth these would be spheroidal hyperbolas. (Readers accustomed to looking at relatively large-scale loran overprinted nautical charts may be surprised at the curvature of the LOPs shown in Figure II_4. Over the short distances covered by a large-scale charts the curvature of the loran LOPs is much less apparent.)

The locus of points that have a constant difference in distance from a master and secondary station describes a mathematical curve termed a hyperbola.

To illustrate, suppose that point A were located at the point shown in Figure II_4, A = (271.9, 200). From equation (II_3), the distance from point A to the secondary would be approximately 212.5 nautical miles. And, from equation (II_2), the distance from point A to the master would be approximately 512.5 nautical miles. Point A, therefore, is 300 miles closer to the X-ray secondary than to the master. Figure II_4 also shows the locus of all such points 300 miles closer to the secondary than to the master this contour is a hyperbola labeled with the number 300. Thus, if we could determine that we were 300 miles closer to the secondary than to the master, we would be located somewhere along this hyperbolic LOP (300).

These hyperbolic LOPs are all curved, with the exception of the LOP where the difference in distance is exactly zero. This is termed the centerline of the system, and is a straight line (rather than a curve) that bisects the baseline. On the curved surface of the earth the centerline is actually a great circle oriented at right angles to the baseline. The baseline extension is also shown in Figure II_4.

Equivalence Between Distance and Time

The contours in Figure II_4 are labeled in terms of distance, but (assuming a constant speed of signal propagation) could equally well be

labeled in terms of time difference (TD). All that is necessary to
calculate the theoretical time difference for any point in Figure II_4
is the speed of signal propagation and the CD of the X-ray secondary.
To a first approximation,[7] loran signals travel at the speed of light it
takes approximately 6.18 usec for the signal to travel one nautical
mile.

Now consider point A again in Figure II_4. The distance from the master
to point A is 512.5 NM, so the signal from the master would take
approximately 6.18 (512.5) = 3,167 usec to reach a vessel at point A.
The arrival of this signal starts the TD measurement in the vessels
loran receiver. When will the signal from the secondary arrive? Recall
that the secondary transmits after an emission delay, equal to the
baseline travel time plus the secondary coding delay. The master and X-
ray secondary are 400 miles apart in this illustration, so the baseline
travel time (or baseline length in usec) is approximately 6.18 (400) =
2,472 usec. Assuming a CD for this secondary of 11,000 usec, 8 the X-
ray secondary would transmit 2,472 + 11,000 = 13,472 usec after the
master. This signal must travel approximately 212.5 NM to reach the
vessel at point A, a travel time of 6.18 (212.5) = 1,313 usec. Thus, in
this example, the signal from X-ray would arrive 13,472 + 1,313 =
14,785 usec after the master transmission. The observed TD at the
vessel is this time, 14,785 usec, minus the time that the master signal
arrives at the vessel, previously calculated as 3,167 usec. The
theoretical TD (based upon these assumptions) at the vessel is 14,785 –
3,167 = 11,618 usec. This calculation is summarized in Table II_2 and
the time lines are shown diagrammatically in Figure II_5.

Loran LOPs can be displayed as distance differences or equivalently as
TDs. Because TDs are measured on the receiver, these are shown on loran
overprinted charts.

Returning now to Figure II_4, the LOP on which point A is located could
be labeled as 300 NM or equivalently as 11,618 usec. Any point on this
LOP is 300 miles closer to the X-ray secondary. Likewise (given the
assumed CD), at any point on this same line, the theoretical TD would
also be 11,618 usec. Because it is the TD rather than the difference in
distance that is measured, it is much more convenient to label the
loran overprinted nautical chart with the TD. More typically the LOPs
shown on a loran overprinted chart would be evenly spaced every 5 or 10
usec. (See Chapter VI.)

With a few added complexities (discussed below) to account for a
nonconstant speed of signal propagation, this is the exact procedure
used for calculation of the theoretical location of the TDs on the
nautical chart.

Though tedious, calculation of the location of lines of constant time
difference is a straightforward exercise in geometry. To a first
approximation, lines of constant difference in distance from two
stations are also lines of constant TD.

_More Exact Calculations

The foregoing calculations assume a constant speed of propagation of
the Loran-C signal. This simplifying approximation is very nearly

correct, but would result in position inaccuracies that exceed the
designed accuracy limits of the Loran-C system. Therefore, it is
necessary to refine this approximation.

Conventionally, this refinement process amounts to applying various
corrections to either the speed of propagation of the loran signal or
equivalently the predicted time required for the signal to traverse a
specified distance. Typically three correction factors, termed phase
factors, are applied. These are defined and summarized in Table II_3.

Primary Phase Factor (PF)

The first of these factors is termed the primary phase factor (PF),
and accounts for the fact that the speed of propagation of the signal
in the atmosphere is slightly slower than in free space (vacuum).
According to Bowditch, the speed of light in vacuum is 161,875 NM/sec
(equivalent to 6.17761 usec/NM), whereas in the atmosphere the speed is
slowed slightly to 161,829 NM/sec (equivalent to 6.17936 usec/NM). This
speed difference is related to the fact that the atmospheric index of
refraction is slightly greater than unity. All Loran-C overprinted
charts and loran receivers incorporate the PF correction.

Secondary Phase Factor

The second correction factor, termed the secondary phase factor (SF),
reflects the fact that the loran groundwave is further retarded when
traveling over seawater as opposed to through the atmosphere. When the
Loran-C signals are transmitted, part of the electromagnetic wave is in
the air, and part penetrates the earth's surface. Seawater is not as
good a electrical conductor as air, so the signals are slowed as they
travel over seawater. The amount of time required for travel over a
specified distance will exceed that calculated using the PF by an
amount equal to the SF. SF is applied as a correction term to the
required travel time rather than as an adjustment to the propagation
speed of the signals. Several equations for SF have been proposed, such
as the so-called Harris polynomials shown below which relate the SF to
the distance traveled, d (in statute miles):

Table II_4 shows the PFs and SFs (from equation II_7)) applied to the
approximate calculation given in Table II_4. For this example, the more
exact calculation differs little from the approximate calculation, but
(depending on the position within the coverage area) these differences
could be numerically larger. As with PFs, SFs are incorporated into all
Loran-C overprinted charts and commercial receivers.

Additional Secondary Phase Factor (ASF)

Application of the PF and SF enables calculation or loran TDs over an
all-seawater path. In practice (see, e.g., Figure II_2), loran signals
travel over a mixed path; partially over land of various
conductivities, and partially over seawater. The correction arising
from the additional retardation of the signal is termed the additional
secondary factor (ASF). ASF is the least predictable of the phase
factors. Many things affect the value of ASF along a signal
transmission path, including conductivity of the soil (which itself

varies with the temperature and water content of the soil), distance traveled over land, etc. The accuracy of a conversion from Loran-C TDs to latitude/longitude (discussed in Chapters III and IV) depends critically on the value of ASF used in the mathematical signal propagation model.

ASF is generally calculated by considering the overall path as separate segments, each having a uniform conductivity value. The ASF of each segment can be computed and then the composite ASF is derived. A popular method of doing this is called Millingtons method, reviewed in Appendix F. Another method of determining ASF is to measure the TDs at a point, compute the TDs at the same point using a mathematical model which assumes an all seawater propagation path, and then determine the difference between the measured and computed TDs. A finite number of such measurements can be made and extrapolated to cover the areas between measurements. ASFs measured in this fashion tend to be more accurate than those computed by Millingtons method. ASFs at a fixed point in the coverage area actually vary with time. To achieve optimum accuracy these temporal ASF changes must be taken into account. ASF variations with time are chiefly caused by changes in soil conductivity due to seasonal weather variations, day/night temperature variations, and local weather activity (thunderstorms, droughts, etc.).

In summary, speed and phase of Loran-C signals are affected by several physical parameters. The primary, secondary, and additional secondary phase factors (PF, SF, and ASF) account for changes due to air, seawater, and land paths, respectively.

ASF Tables

As can be seen from Appendix F, computation of even average (let alone time varying) ASFs is quite tedious, and requires substantial data base describing the relevant conductivity of land or mixed land/water paths. Fortunately these ASFs are incorporated into most Loran-C overprinted charts and also many Loran-C receivers.

Although ASF corrections are incorporated into most (but not all) modern Loran-C receivers, the user should remember that the government is responsible for the accuracy of the ASFs incorporated into ASF tables (see below) and loran overprinted charts. The government is not responsible and cannot guarantee the quality of the ASF databases used in Loran-C receivers, these are strictly the responsibility of the manufacturer.

Additionally, ASFs can be found in a set of tables, called Loran-C Correction Tables, prepared and published by the Defense Mapping Agency, Hydrographic/Topographic Center (DMAHTC). These tables are published in a series of volumes, one for each loran chain. Each volume is organized into a set of pages for each station pair (master and secondary) or rate within the chain. Further, each page of corrections in the table covers an area three degrees in latitude by one degree of longitude. An index permits rapid determination of the appropriate page in the table to find ASFs of interest.

Table II_5 provides an excerpt of a Loran-C Correction Table for the
NEUS (9960) chain and master-Whiskey station pair. This page covers an
area off the mouth of the Delaware Bay between latitudes of 36 0' N and
39 0' N, and longitudes 74 0' W and 75 0' W. Large land bodies and
areas outside the CCZ are represented by blank spaces on the pages (see
Table II_5).

ASF corrections given in this table are to be applied to the measured
TDs, and can be positive or negative. Negative values are prefixed with
a minus (_) sign, while positive values are shown without sign. In some
cases, a negative sign precedes a zero value; this results from
rounding off a value slightly less than zero and indicates the trend of
the correction.

Use of Tables

According to DMAHTC,
ASF tables are published primarily for precision navigators who utilize
electronic computers to convert Loran-C time differences to geographic
coordinates.
 These tables can also be used by navigators using manual plotting
methods for Loran-C navigation.

ASF corrections are typically small (no more than 4 usec), but can be
significant for precise navigation, a point illustrated below.

The ASF correction table can be entered by using the vessels dead
reckoning (DR) position, indicated loran position, or position
determined by other means. ASFs are added algebraically to the measured
(observed) TD of the station pair. For example, suppose that the vessel
were located at the approximate position 39 0' N and 74 30' W, and that
the ASF for the Whiskey station pair were desired. From Table II_5 it
can be seen that the ASF is _0.9 usec. Thus, in this instance 0.9 usec
should be subtracted from the observed TD to obtain a corrected TD.

ASF corrections should be used with caution for areas within ten
nautical miles of land (coastline effect) and should not be used with
charts that provide a corrected lattice.

Care should be taken to ensure that the correct table (hence chain) is
used, and that the correction station pair is considered. Table II_6,
for example, shows how the ASF correction (for the same latitude and
longitude used in the above illustration) varies with the secondary
station and chain. Assuming the location given, the correction
appropriate for the X-ray secondary in the 9960 chain would be 2.9
usec, compared to only 0.3 usec if the 8970 chain were used. It is
particularly important to use the right table (correct chain and
station pair) when determining ASF corrections.

Lest the reader conclude that all this emphasis on refined calculations
is much ado about nothing, the accuracy of the predicted LOP is a key
determinant of the accuracy of the loran position. Loran-C accuracy and

its determinants are explored in some detail in Chapter III. One
important determinant of accuracy is the gradient of the _OP.
Technically, the gradient is the number of ft (meters, yds, etc.)
position difference divided by the number of microseconds. As shown in
Chapter III, these gradients are smallest on the Loran-C baseline, and
increase throughout the coverage area. Even for positions located on
the baseline, however, the gradient is nearly 492 ft/usec. So an ASF
correction of 3 usec, for example, corresponds to a position difference
of at least 1,476 ft in position and perhaps several times greater.
Concern over appropriate ASF corrections is not merely a technical
quibble.

ASF tables are typically not interpolated, as the ASF functions are
generally not linear. Figure II_6, for example, shows smoothed contours
of equal ASF for the data displayed in Table II_5. As can be seen,
there are numerous ridges, saddle points, and local maxima and minima
in the surface described by the data. Simple linear interpolation would
not offer any meaningful increase in accuracy for such a complex
surface. Rather, the correction nearest to the vessels approximate
latitude and longitude should be applied to the appropriate time
difference.

ASF corrections may change over time, as new and more accurate
corrections are determined, so the latest volume should be consulted.
According to some observers (Melton, 1986) the average ASFs are
changing in such areas as Florida's West Coast, due to the construction
of high-rise buildings there.

ASFs (and loran accuracy in general) are much less certain in the
vicinity of the coastline (coastline effect). DMAHTC recommends that
ASF corrections be used with caution for areas within 10 NM of a
coastline.

Groundwave versus Skywave Propagation

Radio energy from a Loran-C transmitter emanates in all directions. The
pulsed Loran-C signal, therefore, may reach the observer by many
propagation paths. These paths are conveniently grouped into two major
categories: (i) groundwave, and (ii) skywave.

The groundwave signal propagates in the atmospheric medium below the
ionosphere (an electrified layer of the atmosphere) and is relatively
well understood and quite predictable. However, the signal strength of
the groundwave is attenuated as it follows the contour of the earth. At
great distances from the transmitter, the groundwave signal is
substantially attenuated.

Skywaves consist of that component of the Loran-C signal which travels
to the observer via reflection from the ionosphere which is actually
comprised of several reflecting layers, assigned letter symbols in
conventional nomenclature. For the 100 kHz frequency of the Loran-C,
this reflection will take place in the lower E or D region of the

ionosphere. The reflection height will vary from approximately 60 kilometers during daylight, to approximately 90 kilometers at night. From the geometry of the reflection, it is obvious that the skywave signal must travel a longer distance to reach an observer and will arrive after the corresponding groundwave generally after a time lapse of from 35 usec to 1000 usec after the groundwave (depending upon the height of the reflecting layer in the ionosphere). Because skywaves do not travel over the surface of the earth, these are not attenuated to the same extent as the groundwave. In consequence, at long distances, the skywave signal may be very much stronger than the groundwave signal. The skywave can cause distortion of the received groundwave signal in the form of fading and pulse shape changes generally given the name skywave contamination.

Although it is possible to develop position information from skywave signals (and, indeed, skywaves were used in early loran), the most accurate navigation requires the use of the loran groundwave. (Use of skywaves for navigation is discussed briefly in Appendix H.)

The reason why groundwaves are preferred over skywaves for accurate navigation is that the propagation conditions (in the ionosphere) are not stable, but change from day-to-day and even hour-to-hour, which vastly complicates the problem of prediction of arrival times for skywaves. The skywave, therefore, is generally regarded as a nuisance, and the Loran-C system has been designed in part to minimize the possible influence of skywaves on groundwave reception and tracking.

Pulse Architecture and
Related Technical Matters

It is noted above that the Loran-C system uses pulsed transmission nine pulses for the master and eight pulses for the secondary transmissions. Figure II_7 shows this overall pulse pattern for the master and three secondary transmitters (X-ray, Yankee, and Zulu). Shown also in Figure II_7 is an exploded view of the Loran-C pulse shape. It consists of sine waves within an envelope that might loosely be described as teardrop shaped, and is referred to technically as a t-squared pulse. (The equation for the envelope is also included in Figure II_7.) This pulse will rise from zero amplitude to maximum amplitude within the first 65 usec and then slowly trails off or decays over a 200_300 usec interval. The pulse shape is designed so that 99% of the radiated power is contained within the allocated frequency band for Loran-C of 90 kHz to 110 kHz.

The rapid rise of the pulse allows a receiver to identify one particular cycle of the 100 kHz carrier. Cycles are spaced approximately 10 usec apart. The third cycle of this carrier within the envelope is used when the receiver matches the cycles. The third zero crossing (termed the positive 3rd zero crossing) occurs at 30 usec into the pulse. This time is both late enough in the pulse to ensure an appreciable signal strength and early enough in the pulse to avoid skywave contamination from those skywaves arriving close after the corresponding groundwave.

Phase Coding
Within each pulse group from the master and secondary stations, the
phase of the radio frequency (RF) carrier is changed systematically
from pulse-to-pulse in the pattern shown in Figure II_8. This procedure
is known as phase coding.   The patterns "A" and "B" alternate in
sequence. The pattern of phase coding differs for the master and
secondary transmitters. Thus, the exact sequence of pulses is actually
matched every two GRIs an interval known as a phase code interval
(PCI). [9]

Phase coding enables the identification of the pulses in one GRI from
those in an earlier or subsequent GRI. Just as selection of the pulse
shape and standard zero crossing enable rejection of certain skywaves,
phase coding enables rejection of others; late airway skywaves will
have a different phase code from the groundwave. Because the master and
secondary signals have different phase codes, these can be
distinguished by the loran receiver. Phase coding also offers other
technical benefits.

Blink Coding

The Loran-C system also permits the secondary transmissions (more
specifically the first two pulses of the secondary pulse group) to
blink.
 This secondary blink can be detected by the loran receiver, and is
used to warn users that the loran signal is unreliable and should not
be used for navigation. (The specifics of the blink display differ from
receiver-to-receiver in some cases a blink alarm on the receiver will
light, in others the displayed TDs simply blink on and off.) Blink
alarms warn that the signal power, TD, or ECD is out-of-tolerance (OOT)
and/or that an improper phase code or GRI is being transmitted. The
blink coding contributes significantly to the integrity of the loran
system.

When secondary blink is enabled, the first two pulses of the affected
secondary are blinked at a four-second cycle; about 3.6 seconds off and
about 0.4 seconds on. Secondary blink is used to advise users of
potential problems. The loran system also has the capability to blink
the master signal. Master blink is used for internal communications,
and does not indicate a system malfunction. Most modern user receivers
are not programmed to detect master blink.

Concluding Comments

Table II_7 summarizes some of the key technical features of the Loran-C
system and reasons for their inclusion. At a detailed level, this
system is highly complex, but these complexities are essential to
create a highly accurate, reliable, and easy to use long-range system.